BURST PRESSURE PREDICTION OF COLLINEAR CRACK IN STEEL PIPELINE.

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ABSTRACT

The predictions of pipeline burst pressure in the early stage are very importance in order to provide assessment for future inspection and maintenances activities. The failures of pipelines contribute to economic implications, fatal injuries and also constitute serious hazards to the environment due to leakage. This project is a study on interaction effect of the distance between cracks for material grade B steel pipe using finite element analysis (FEA). The objectives for this project are to study the interaction of two linear cracks and analyze the maximum pressure defect for various distances between crack and crack length. This project include the analysis of the material grade B steel by using MSC Patran 2008 r1 software as pre-processor and MSC Marc 2008 r1 software as a solver. This analysis investigates one failure criterions that is von Mises stress as to predict the failure of defective pipe. Half of pipe was simulated by applying the symmetrical condition. The pipe is modeled in 3D with outer diameter of 60.5 mm, wall thickness of 4 mm and different defect parameters. Result shows that the maximum pressure increases when the distance between cracks increase and the crack length decrease. The results have been compared to available design codes for corroded pipelines such as ASME B31G, Modified ASME B31G and DNV RP F101. The comparison with design codes have shown that FEA burst pressure gives higher values.

ABSTRAK

Ramalan-ramalan tekanan letus saluran paip di peringkat awal adalah sangat penting untuk menyediakan penilaian bagi pemeriksaan pada masa akan datang dan aktiviti penyelenggaraan. Kegagalan saluran paip minyak dan gas menyumbang kepada implikasi ekonomi, kecederaan maut dan juga merupakan suatu bahaya yang serius kepada alam sekitar yang berpunca daripada kebocoran. Projek ini adalah bertujuan untuk mengkaji kesan hubungan rekahan ke atas besi gred B dengan menggunakan perisian (FEA). Objektif untuk kajian ini adalah untuk mengkaji interaksi di antara dua rekahan yang selari dan untuk mengkaji tekanan tertinggi ke atas perbezaan jarak antara rekahan dan tekanan ke atas panjang rekahan. Projek ini melibatkan analisa besi gred B dengan menggunakan perisian MSC Patran 2008 r1 sebagai pra-pemproses dan MSC Marc 2008 perisian r1 sebagai penyelesai. Didalam analisis ini, satu kriteria kegagalan iaitu tekanan von Mises digunakan untuk meramalkan kegagalan paip rosak. Separuh daripada paip disimulasi dengan menggunakan keadaan simetri. Paip dimodel dalam bentuk 3D dengan diameter luar 60.5 mm, ketebalan dinding 4 mm dan parameter kecacatan yang berbeza. Keputusan menunjukkan bahawa tekanan yang pecah meningkat apabila jarak antara rekahan menigkat dan panajang rekahan berkurang. Keputusan telah berbanding kod reka bentuk tersedia untuk saluran paip berkarat seperti ASME B31G, Modified ASME B31G dan DNV RP F101. Perbandingan dengan kod reka bentuk yang ada telah menunjukkan bahawa tekanan letus FEA memberikan nilai yang lebih tinggi.

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LIST OF SYMBOLS

t	Pipe thickness
d	Distance between cracks
$2c$	Crack length
σ_{UTS}	Ultimate tensile strength, MPa
σ_Y	0.2% offset yield strength, MPa
E	Young modulus
A_0	Cross-sectional area
L_0	Length
P	Pressure
K	Strain hardening coefficient
n	Strain hardening exponent
ν	Poisson's ratio
ε_f	Fracture strain
σ_e	Engineering stress
σ_t	True stress
ε_e	Engineering strain
ε_t	True strain
mm	Millimetre
MPa	Mega Pascal
%	Percent
kN	kilo Newton
Cu	Cuprum
H_2	Hydrogen
O_2	Oxygen

LIST OF ABBREVIATIONS

2D	Two Dimension
3D	Three Dimension
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
API	American Petroleum Institute
ANSI	American National Standards Institute
DNV	Det Norske Veritas
FEA	Finite Element Analysis
FEM	Finite Element Method
HIC	Hydrogen Induced Cracking
RP	Recommended Practice
SCC	Stress Corrosion Cracking
SOHIC	Stress-Oriented Hydrogen Induced Cracking
MSS	Maximum Shear Stress
CSV	Comma-Separated Values
BC	Boundary Condition
CAD	Computer Aided Design

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain about the introduction of this project. This chapter will consist of project background, problem statement, objectives, scope of study, and project flow chart. All this information is important before furthering to the analysis and study later.

1.2 PROJECT BACKGROUND

The increasing number of aging pipelines in operation is significantly increased the number of accidents such gas leaking and bursting pipeline. Failure due to corrosion defect has been major concern in maintaining pipeline integrity (Y.K. Lee et al., 2005). Most of the pipelines are allowed to operate after calculating the maximum internal or external product being transport. Accurate burst pressure prediction is important to structural the design and integrity assessment of the pipeline. The bursting of the pipe with wall thinning accompanies a bulge due to inelastic deformation at the wall. Therefore it is good to predict the burst pressure by considering the plastics deformation before bursting occur. The deformation characteristic is depending on the material and this study focus on material grade B. In this study, 3D elastic plastic FEA was conducted to examine the interaction between the distance between cracks and the cracks length on the failure pressure. Nonlinear finite element is used to analysed the interaction of multiple defect. The validity of the FEA was confirmed by comparing its result with industry models.

1.3 PROBLEM STATEMENT

Nowadays the increasing demand in oil and gas industry has influent the development of pipeline with the large diameter, thin in thickness, and made from high steel material so it can operate in high pressure. With increasing their age, the pipeline remaining strength depends on a few factors such operational condition, defect cause by construction, third party damage, corrosion and soil movement.

Corrosion is one of the defects in pipeline. The defect due to the corrosion at the pressurized pipeline can cause a high risk of failure and the pipe need to undergo the reliable assessment before it can be allowed to operate. Wall thinning caused by corrosion on the inner or outer surfaces of the pipelines will generate stress concentration on the pipe wall (Y.K. Lee et al., 2005). The highest stress and strain value will occur at the corrosion defect area, therefore the failure of the pipelines are usually expected at this location. Integrity assessment of corroded pipeline is very vital in oil and gas industry. Better understanding is required to reduce the conservatism involved in the current assessment method. There are many reliable assessment can be used to predict the burst pressure such ASME B31G, Modified ASME and DNV. Previous research has found out that finite element analysis has become a reliable engineering approach towards achieving actual results. Many consultant companies realize that it is difficult to have a finite element modeling of the offshore corroded pipeline as the modeling need further understanding and detail research on each data. In this research, finite element analysis will be implemented comparing with the available industry model as it is a higher demand in the oil and gas industry. This thesis will be a start and guidance in helping industries towards achieving accurate prediction of failure on defect pipelines.

1.4 OBJECTIVES

For this project, two main objectives are listed:

i. To determine the maximum pressure of defect pipe using finite element analysis (FEA).
ii. To study the interaction of the distance between two cracks.
iii. To compare the FEA results with the available design code such ASME B31G, Modified ASME B31G, and DNV-RP-F101.

1.5 SCOPE OF STUDY

This study was focused on the interaction of distance between two cracks in a pressurized pipeline. The scope consists of:

i. The geometry of the crack is rectangular cross section.
ii. The crack is at the outer surface of the pipeline.
iii. MSC Patran 2008 r1 software is used as pre-processor and MSC Marc 2008 r1 is used as solver to simulate the cracks.
iv. Material used is Material Grade B.
v. FEA results will be compared with the available design code such ASME B31G, Modified ASME B31G, and DNV-RP-F101.

1.6 PROJECT FLOW CHART

A flow chart is a graphical representation of a process. Each step in the process is represented by a different symbol and contains a short description of the process step. They are linked together with arrows showing the process flow direction. Flow chart is very important in doing research because it helping the viewer to understand and visualize the process flows. The terminology of work planning in this project is shown in Figure 1.1.

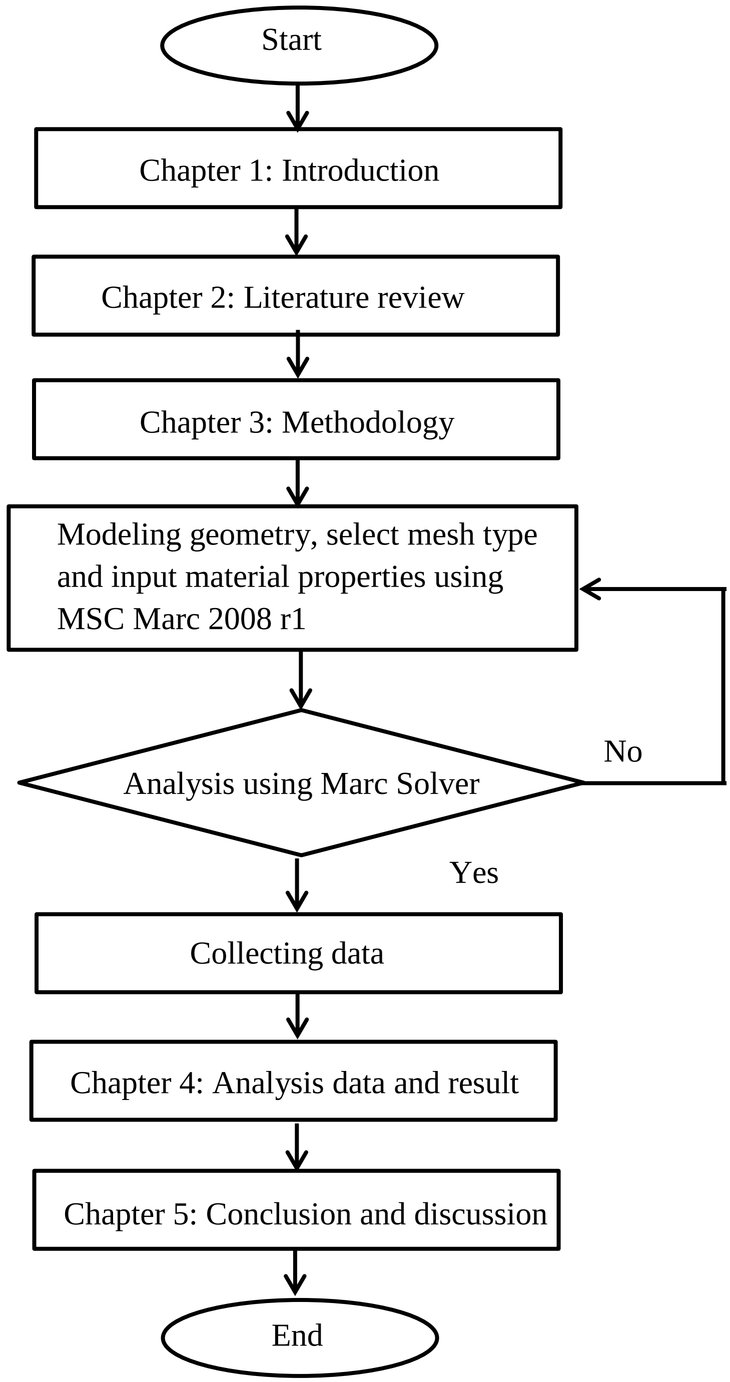

Figure 1.1: Project flow chart.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will briefly explain about the burst pressure model, material properties, type of defect, failure criteria and cause of failure in pipeline. The sources for this literature are taking from journals, articles, and books. Literature review is important to provide some information about previous research and help to facilitate when conducting this project. All this information is important to start the analysis and further study.

2.2 INTRODUCTION TO PIPELINE

Pipeline is a long pipe underground commonly used to transport oil and natural gas over long distances. For gases and liquids or any chemically stable substance can be sent through a pipeline. In general, pipelines can be classified in three categories depending on purpose that is gathering pipelines, transportation pipelines and distribution pipelines. Gathering pipelines is a group of smaller interconnected pipelines forming complex networks with the purpose of bringing crude oil or natural gas from several nearby wells to a treatment plant or processing facility (Kim et al., 2008). In this group, pipelines are usually short a couple of hundred meters and with small diameters. Also sub-sea pipelines for collecting product from deep water production platforms are considered gathering systems.

Transportation pipelines mainly long pipes with large diameters, moving products include oil, gas, and refined products between cities, countries and even continents. These transportation networks include several compressor stations in gas lines or pump stations for crude and multiproduct pipelines (Beaver and Thompson, 2006). Distribution pipelines composed of several interconnected pipelines with small diameters, used to take the products to the final consumer. Feeder pipelines were used to distribute gas to houses and business downstream.

2.3 MATERIAL PROPERTIES

2.3.1 Carbon Steel

Carbon steel is the most widely used engineering material in the overall of steel production worldwide (Morrow, 2010). Carbon steel can be defined as steel where the main interstitial alloying element is carbon. Carbon steel can be described as the structural material which is abundantly available, inexpensive, adequate formability and weldability, and has adequate mechanical properties but has a high general corrosion rate (Kadhim, 2011).

Although carbon steel is always related to the low corrosion resistance or high general corrosion rate, it is still the most widely used engineering material in this world. It is well known that carbon steel corrodes rapidly in seawater environment and requires adequate protection depending on the type of application. Though carbon steel is the most prone to corrosion, it is the least expensive of the most commonly perforated metals compared to other type of structural material. Carbon steel is used in large tonnages in marine applications, nuclear power and fossil fuel power plants, transportation, pipelines, mining, and construction (Kadhim, 2011).

2.3.2 Types of Carbon Steel

Carbon steel can be divided into five groups based on its carbon content which are low carbon steel, mild steel, medium carbon steel, high carbon steel and ultra-high carbon steel. Typical groups of carbon steels are tabulated in Table 2.1 and each group of carbon steel is provided with some examples which start with American Iron and Steel Institute (AISI). There are a total of five groups of carbon steel which shows different characteristics are discussed in Table 2.1. Different groups of carbon steel are applied in different application in worldwide and it depends on the characteristic of the carbon steel and the requirement of the application.

Table 2.1: Types of carbon steel.

Carbon steel types	Example AISI No.	% of carbon	Explanation
Low carbon steel	1010, 1012	0.05-0.15	It is neither ductile nor brittle. It is normally used when huge quantities of steel and high surface finish are required. It is used in the form of structural steel such as sheets, strips, rods and wires.
Mild steel	1018, 1020	0.16-0.29	Its price is usually low and it provides the material properties which are acceptable under many circumstances. It is characterized by a low tensile strength, but it is malleable, good machinability, and cheap. It is used to produce ship plates, welded turbines, boiler tubes and camshafts.
Medium carbon steel	1035, 1038	0.30-0.59	It is stronger and possesses better hardness and tensile strength but less ductility than mild steel. It has good machinability, deep hardening properties and fantastic wear resistance. It is used in automotive components which required higher strength such as stronger nut, large forgings, and high tensile tubes.
High carbon steel	1055	0.6-0.99	It is very strong, utilized in high-strength wires and springs. Ductility and machinability of steel decreases with the increase in carbon content. It is used in produce cold chisel, wrenches, jaws, hacksaw blades and railway service.
Ultra-high carbon steel		1-2	It could be tempered for greater hardness. It is utilized for special purposes such as non-industrial-purpose knives, punches or axles.

Source: Ashby and Johnson (2009)

2.3.3 Application of Carbon Steel in Seawater

Although carbon steel is highly related to the limited corrosion resistance compared to other common types of steels such as stainless steel, carbon steels are commonly used in seawater for structural applications such as ship hulls, offshore platforms, sheet piles and coastal facilities as well as seawater piping systems. All these applications required high corrosion resistance material since the medium environment of the applications is seawater which can increase the corrosion rate of the material (Kadhim, 2011). Basically, seawater in the ocean in the world has a salinity which is about 3.5 %. In other words, each litre by volume of seawater has approximately 35 grams of dissolved salts (predominantly sodium (Na^+) and chloride (Cl^-) ions).

Carbon steel is preferred in a seawater environment compared other types of material since carbon steel exhibit low initial cost compared with other materials, the ready availability of material and components and the existence of widely used and accepted welding procedures. However, the rate of corrosion of carbon steel is much higher and this becomes the main barrier of the usage of carbon steel in seawater environment. Basically, a system that produced or designed using carbon steel is much cheaper since carbon steel is inexpensive but the system is larger, heavier and shorter life compared to other structural material. Thus, the failures of the structure may occur earlier and it is within a few years and complete replacement is required compared to other better corrosion resistance structural material (Bennett, 2002).

However, in order to increase the corrosion resistance of carbon steel in seawater environment, method of coatings is largely applied. Coating is a famous and widely used method to protect the low corrosion resistance material such as plain carbon steel but it also increases the initial costs since more process is needed compared to plain carbon steel. Coating is applied on the both surfaces which are inner and outer surface in order to increase the corrosion resistance of the material. However, by applying a coating on the surface of the material, it introduces complications into the fabrication procedures, such as the need for a local removal prior to welding and re-application afterwards

(Morrow, 2010). Besides that, heat treated carbon steel can be used compared to plain carbon steel in order to improve the corrosion resistance of the carbon steel. Heat treated carbon steel has better mechanical properties and corrosion resistance compared to the plain carbon steel since different microstructure existed in the material.

2.4 CORROSION CONCEPTS

Corrosion can be defined as degradation of quality and properties in a material due to the chemical reaction between the components of the material and the surrounding during the electrochemical process (Iversen and Leffler, 2010). Electrochemical process is a general process which requires the presence of an anode, a cathode, an electrolyte, and an electrical circuit in order to active the reaction.

First, the metal at the anode is dissolved and the electrons are produced from the anode is shown in Figure 2.1. The number of electrons produced depends on the type of the metal used. After the electrons produced at the anode, the corrosion current is generated by the electrons and the electrons are transferred to the cathode through the electrolyte as a transfer medium. Equation (2.1) shows the general reaction that occurs at the anode (Iversen and Leffler, 2010).

$$M \longrightarrow Mn^{+} + e^{-} \qquad (2.1)$$

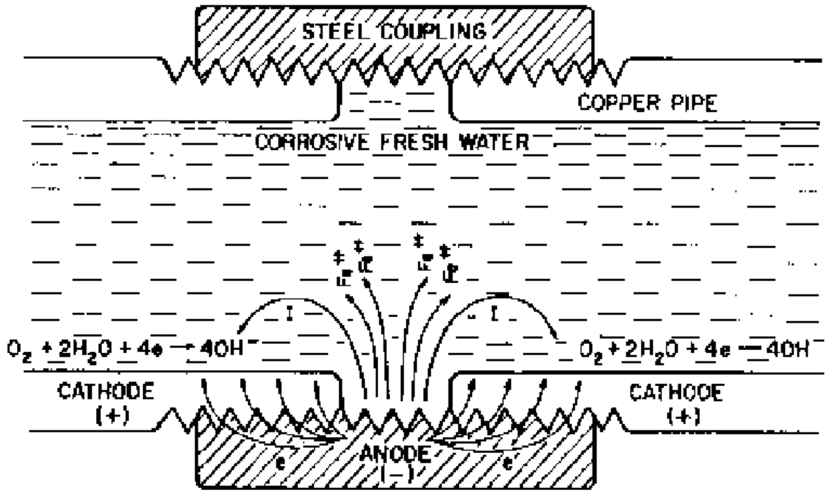

Figure 2.1: The basic corrosion cell.

Source: Iversen and Leffler (2010)

The reaction at the anode shows a loss of electrons, or oxidation is clearly shown in Figure 2.1. The electrons produced at the anode flow to the cathode through the electrolyte which initiates a reaction to occur at the cathode. The reaction in cathode depends on the medium of transfer which can be divided into three groups which are acidic solution, alkaline solution and neutral solutions. All of these reactions in each solution involve a gain of electrons and a reduction process which occurs at the cathode is shown in Equation (2.2) which in neutral solution. If the medium is in alkaline and neutral aerated solutions, the predominant cathodic reaction is shown in Equation (2.2) (Iversen and Leffler, 2010). The number of electrons produced at the anode must equal the number of electrons gained at the cathode since there can be no net gain or loss of electrons.

$$O_2 + 2H_2O + 4e^{-} \longrightarrow 4(OH^{-}) \qquad (2.2)$$

If Fe is placed at the anode which exposed to aerated, corrosive water, the anodic reaction is shown in Equation (2.3) which oxidation is occurred. However, at the cathode, reduction of oxygen is occurred as shown in Equation (2.1) (Iversen and

Leffler, 2010). Based on the Equation (2.3), two electrons are produced during the reaction at the anode. However, based on Equation (2.2), four electrons are required in order to balance the reaction at the cathode.

$$Fe \rightarrow Fe^{2+} + 2e^{-} \tag{2.3}$$

Based on the concept of reaction, the number of electrons produced at the anode must equal the number of electrons gained at the cathode since there can be no net gain or loss of electrons. Thus, the anodic reaction is modified and shown as Equation (2.4) while the cathodic reactions would be similar to the previous equation (Iversen and Leffler, 2010). Finally, an overall oxidation-reduction reaction is shown in Equation (2.5) which summarized the oxidation-reduction reaction occurred at the cathode and anode.

$$2\ Fe \rightarrow 2Fe^{2+} + 4e^{-} \tag{2.4}$$

$$2Fe + O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4(OH^{-}) \tag{2.5}$$

However, after the dissolution at anode, the ferrous ions or known as Fe2+ generally oxidize to ferric ions (Fe^{3+}) are shown in Equation (2.6) and these combine with hydroxide ions (OH^{-}) which formed at the cathode to give a corrosion product called iron oxide or in general term called as rust. There are several forms of rust which can be distinguished visually or by using spectroscopy. Basically rust consists of iron (III) oxides, $Fe2O_3 \cdot nH2O$ and iron (III) oxide-hydroxide, FeO(OH), or $Fe(OH)_3$ are shown in Equation (2.7) and (2.8). It can be concluded that anodic dissolution of metal occurs electrochemically while the insoluble corrosion products are formed by a secondary chemical reaction is shown in the equation below (Iversen and Leffler, 2010).